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RESEARCH MEMORANDUM

COMPARISON OF THE COMBUSTION PERFORMANCE OF SHELL UMF, GRADE C, AND MIL-F-5624C, GRADE JP-5, FUELS IN A HEAVY-DUTY XRJ47-W-9 RAM-JET ENGINE

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RESEARCH MEMORANDUM

COMPARISON OF THE COMBUSTION PERFORMANCE OF SHELL UMF, GRADE C, AND MIL-F-5624C, GRADE JP-5, FUELS IN A HEAVY-DUTY XRJ47-W-9 RAM-JET ENGINE

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4127

SUMMARY

Comparable combustion performance data for Shell UMF, grade C, and MIL-F-5624C, grade JP-5, fuels were obtained using a heavy-duty version of the XRJ47-W-9 ram-jet engine operated in a 2.75 Mach number free-jet facility. Data were obtained for the two fuels over a range of fuel-air ratios, engine airflows, and engine-inlet temperatures. The test conditions were selected to provide combustor-inlet conditions approximately representative of those which would be encountered over a range of altitudes and flight Mach numbers. The variation of combustion efficiency with fuel-air ratio for the two fuels is compared at the several inlet conditions. The pilot-burner ignition and operating limits with both fuels are also included.

In general, the combustion efficiency with Shell UMF, grade C, fuel was 1 to 4 points lower than with MIL-F-5624C, grade JP-5, fuel.

CD-1

INTRODUCTION

The rocket-powered booster and ram-jet-powered XSM-64A long-range surface-to-surface missile of the WS-104A program are both to use the same fuel; therefore, the fuel characteristics must be compatible to both booster and missile. The fuel originally specified for use is MIL-F-5624C, grade JP-5. Studies by the booster-and-missile manufacturer have indicated that fuels obtained under this specification would be unsatisfactory for either the booster or the missile. The variable fuel properties permitted by the specification would cause difficulty in maintaining the correct mixture ratio to the rocket engines. The thermal-stability characteristics of fuels obtained under the specifications are such that these fuels would be unsatisfactory for the missile because of gum-forming tendencies and the resultant detrimental effect on the missile fuel-system reliability.

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To overcome the aforementioned deficiencies of MIL-F-5624C, grade JP-5, fuel for the WS-104A, the booster-and-missile manufacturer prepared a special fuel specification. This proposed specification placed stringent restrictions on the physical properties and constituents of the fuel. A fuel that essentially meets these specifications is designated Shell UMF, grade C. Preliminary testing of this fuel, in the booster rocket engines and in terms of thermal stability, indicated that it had significant advantages over JP-5 fuel for the booster and missile.

As a part of the over-all program to evaluate the suitability of
Shell UMF, grade C, fuel for the WS-104A, an investigation was conducted 4127
at the NACA Lewis laboratory to evaluate the combustion characteristics of the fuel in a full-scale ram-jet combustor of the same size and general type proposed for use in the XSM-64A missile. This report compares the combustion efficiency, stability, and pilot-burner operating limits of the combustor using Shell UMF, grade C, and MIL-F-5624C, grade JP-5, fuels. A heavy-duty version of the XRJ47-W-9 ram-jet engine, developed for use in the XSM-64 missile and installed in a 2.75 Mach number free-jet facility, was used for the tests. Combustor data were obtained with both fuels over a range of fuel-air ratios, engine airflows, and engine-inlet temperatures. The test conditions were selected to provide combustor-inlet conditions approximately representative of those which would be encountered over a range of altitudes at inlet temperatures corresponding to the 3.25 flight Mach number of the XSM-64A missile, the test Mach number of 2.75, and an intermediate Mach number.

APPARATUS

Installation

Installation of the engine in the free-jet facility is shown in figure 1. The supersonic diffuser inlet was mounted within the Mach cone of the 2.75 Mach number supersonic nozzle. Air bypassed around the engine was diffused in the jet diffuser to the ambient pressure in the exhaust system.

Engine

The heavy-duty, 2.75 flight Mach number, D-49 inlet diffuser and a heavy-duty version of the XRJ47-W-9 ram-jet-engine combustor with water-cooled combustor shell and exhaust nozzle were used throughout the investigation. A sketch of the combustor showing the flameholder, adjustable fuel-injection system, and basic dimensions is presented in figure 2.

The flameholder was composed of three annular gutters interconnected by longitudinal gutters. Two configurations were used during the

investigation. Configuration A (fig. 3(a)) has ten longitudinal flameholder elements connecting the middle and outer annular elements; configuration B (fig. 3(b)) has fifteen longitudinal elements connecting the corresponding annular elements. The pilot burner of configuration A used a slotted flameholder and that of configuration B used a cone flameholder. The pilot burner and inner annular flameholder element of configuration B were 6 inches downstream of the location of the corresponding elements of configuration A, as shown by the dashed lines in figure 2. The pilot burner of each configuration included a sparkplug for ignition purposes.

Shown in figure 4 is a photograph of the heavy-duty adjustable fuel-injection system used with both flameholder configurations. The fuel system had 65 spring-loaded variable-area fuel-spray nozzles, each rated at 860 pounds per hour fuel flow at a pressure of 300 pounds per square inch gauge. All fuel nozzles were pointed downstream.

Instrumentation

Location of the engine instrumentation is shown in figure 1. The inlet and outlet temperatures and the flow of the water used to cool the combustor shell and exhaust nozzle were also measured.

Fuels

An analysis comparison of the two fuels used during the tests is given in table I. The fuels were supplied to the engine fuel system at a temperature of approximately 80° F.

PROCEDURE

The combustion performance characteristics of Shell UMF, grade C, and MIL-F-5624C, grade JP-5, fuels were determined over a range of fuel-air ratios from about 0.025 to approximately the value which would result in critical operation of the supersonic inlet diffuser at the following test conditions:

Nominal engine airflow, $W_{a,0}$, lb/sec	Free-stream conditions		
	Nominal total temperature, °R		
	1210	1060	990
	Nominal total pressure, lb/sq ft abs		
120	4240	----	3850
100	3545	3310	3205
80	2825	2645	2555
60	2110	1970	1900

The test conditions were selected to provide combustor-inlet conditions approximately representative of those which would be encountered over a range of altitudes at inlet temperatures corresponding to the 3.25 flight Mach number (free-stream total temperature, 1210° R) of the XSM-64A missile, the test Mach number of 2.75 (free-stream total temperature, 990° R), and an intermediate Mach number.

At each inlet total temperature, the combustor performance data were obtained over a range of fuel-air ratios at the selected airflows using first MIL-F-5624C, grade JP-5, fuel, and then Shell UMF, grade C, fuel; check runs were subsequently made at each airflow with the JP-5 fuel. The data at an inlet total temperature of 1210° R were obtained using combustor configuration A. Because of damage to combustor configuration A in the aforementioned testing, the data at inlet total temperatures of 1060° and 990° R were obtained using combustor configuration B. 4127

Pilot-burner operating limits of combustor configuration B were investigated with an inlet total temperature of 990° R at engine airflows of 60 and 80 pounds per second; these were selected as the most severe conditions in order to observe any significant differences in the operating limits with the two fuels. Pilot-burner lean ignition limits were found by increasing the pilot fuel flow with the spark on until ignition occurred. Rich ignition limits were obtained by reducing the pilot fuel flow from a value beyond rich blowout until ignition occurred. Lean and rich pilot-burner blowout limits were obtained without use of the spark ignition.

The symbols and methods of calculations used in this report are given in the appendixes.

PRESENTATION OF RESULTS

A complete tabulation of the combustor performance data obtained, together with the test conditions, is presented in table II for MIL-F-5624C, grade JP-5, fuel and in table III for Shell UMF, grade C, fuel.

For Shell UMF, grade C, fuel, the variation of combustion efficiency with fuel-air ratio at the various engine airflows is shown in figures 5(a), (b), and (c) for inlet total temperatures of 1210°, 1060°, and 990° R, respectively. MIL-F-5624C, grade JP-5, and Shell UMF, grade C, fuels are compared directly on the basis of the variation of combustion efficiency with fuel-air ratio at each inlet condition in figures 6, 7, and 8.

Pilot-burner operating limits for both fuels are presented in figure 9 for engine airflows of 60 to 80 pounds per second at an inlet total temperature of 990° R.

STATEMENT OF RESULTS

At an inlet total temperature of 1210° R, corresponding to the 3.25 flight Mach number of the XSM-64A missile, the peak combustion effi-
4127 ciency with Shell UMF, grade C, fuel varied from 0.89 to 0.92 as the engine airflow was increased from 60 to 120 pounds per second. The combustion efficiency with this fuel, in general, was 1 to 3 points lower than with MIL-F-5624C, grade JP-5, fuel over the range of fuel-air ratios and engine airflows at the above inlet temperature. At the lower inlet total temperatures, the combustion efficiency decrement of the Shell UMF, grade C, fuel in general was 1 to 4 points at fuel-air ratios above 0.030 and somewhat greater at lower fuel-air ratios.

The operating limits of the pilot burner were similar for the two fuels.

Lewis Flight Propulsion Laboratory
National Advisory Committee for Aeronautics
Cleveland, Ohio, November 19, 1956

APPENDIX A

SYMBOLS

The following symbols are used in this report:

A	area, sq ft
C_D	exhaust-nozzle flow coefficient, 0.99
f/a	fuel-air ratio
h_f	fuel heating value, Btu/lb
K	engine airflow parameter
P	total pressure, lb/sq ft abs
T	total temperature, $^{\circ}R$
W_a	airflow, lb/sec
W_f	fuel flow, lb/sec
η_b	combustion efficiency
$\Delta H_{cooling\ water}$	cooling water enthalpy rise, Btu/sec

Subscripts:

eff	effective
id	ideal
0	free-stream condition (free-jet nozzle inlet)
3	supersonic diffuser outlet
6	engine exhaust-nozzle throat

4127

APPENDIX B

CALCULATIONS

Airflow. - The engine was operated supercritically throughout the investigation, and engine inlet airflow was determined from the relation

4127

$$W_{a,0} = \frac{KP_0}{\sqrt{T_0}} \tag{1}$$

Value of the airflow parameter K varied with the facility pressure ratio and engine inlet (or free-stream) total temperature, and was determined from an airflow calibration of the engine.

Fuel-air ratio. - The fuel-air ratio was calculated directly from measured fuel flow and airflow:

$$f/a = \frac{W_f}{W_a} \tag{2}$$

Combustion efficiency. - Combustion efficiency was determined by the ratio of corrected ideal fuel-air ratio and actual fuel-air ratio:

$$\eta_b = \frac{(f/a)_{id} + (f/a)_{cooling\ water}}{f/a} \tag{3}$$

The ideal fuel-air ratio is the theoretical fuel-air ratio required (assuming 100 percent combustion efficiency) to obtain the measured values of engine total-pressure ratio P_6/P_0. Values of ideal fuel-air ratio for both fuels were obtained from charts of $(f/a)_{id}$ against P_6/KP_0 for various values of engine-inlet total temperature. Calculations of these charts used the following values:

	MIL-F-5624C, grade JP-5	Shell UMF, grade C
Fuel heating value, Btu/lb	18,600	18,525
Fuel hydrogen-carbon ratio	0.161	0.150
Effective engine exhaust-nozzle throat area, sq ft		6.805

Effective engine exhaust-nozzle area $A_{6,eff}$ was determined from

$$A_{6,eff} = A_6 C_D \tag{4}$$

The cooling-water fuel-air ratio accounts for the heat loss to the combustor and engine exhaust-nozzle cooling water:

$$(f/a)_{\text{cooling water}} = \frac{\Delta H_{\text{cooling water}}}{h_f\, W_{a,0}} \tag{5}$$

The cooling-water enthalpy rise was determined from the measured flow and temperature rise of the engine cooling water.

4127

4127

CD-2

TABLE I. - FUEL ANALYSIS

Fuel properties	Shell UMF, grade C	MIL-F-5624C, grade JP-5
Distillation, °F		
Initial boiling point	438	346
Percent evaporated		
5	446	360
10	449	370
20	453	380
30	458	390
40	462	400
50	468	410
60	474	420
70	482	434
80	492	448
90	508	464
95	526	476
Final boiling point	548	500
Residue, percent	1.1	1.2
Loss, percent	0	0
Analine point, °F	159.1	146.5
Gravity, °API	34.5	43.0
Specific gravity, 60°/60° F	0.852	0.811
Hydrogen-carbon ratio	0.150	0.161
Lower heating value, Btu/lb	18,525	18,600

TABLE II. - INLET CONDITIONS AND COMBUSTOR PERFORMANCE DATA FOR MIL-F-5624C, GRADE JP-5, FUEL

Engine airflow, $W_{a,0}$, lb/sec	Fuel-air ratio, f/a	Free-stream total pressure, P_0, lb/sq ft abs	Diffuser total-pressure recovery, P_3/P_0	Engine total-pressure ratio, P_6/P_0	Combustor total-pressure ratio, P_6/P_3	Engine inlet total temperature, T_0, °R	Engine airflow parameter, K	Pilot fuel flow, lb/sec	Combustion efficiency, η_b
Nominal inlet temperature, 990° R; combustor configuration B									
121.28	0.0237	3859	0.5035	0.3548	0.7046	989	0.9884	0.13	-----
120.32	.0239	3830	.5084	.3726	.7329	990	.9883	.13	0.460
120.78	.0281	3841	.5439	.4569	.8401	988	.9883	.15	.821
121.23	.0343	3854	.5903	.4992	.8457	987	.9883	.17	.921
120.95	.0346	3856	.5869	.4984	.8493	993	.9884	.17	.913
121.10	.0393	3850	.6122	.5231	.8545	987	.9883	.17	.929
120.91	.0440	3857	.6217	.5395	.8678	994	.9884	.17	.914
100.82	.0243	3201	.5086	.3749	.7371	988	.9884	.12	.465
100.18	.0248	3206	.5062	.3874	.7652	1001	.9884	.13	.632
100.85	.0292	3206	.5412	.4529	.8369	987	.9884	.12	.795
100.86	.0342	3202	.5803	.4959	.8547	985	.9884	.15	.904
100.82	.0344	3201	.5889	.4998	.8488	985	.9884	.15	.919
100.87	.0391	3203	.6047	.5176	.8560	991	.9884	.15	.908
100.47	.0449	3203	.6266	.5448	.8695	993	.9884	.15	.920
101.08	.0452	3203	.6275	.5435	.8662	981	.9884	.15	.896
100.50	.0498	3203	.6416	.5616	.8754	992	.9884	.15	.910
80.40	.0249	2556	.5106	.3815	.7471	988	.9886	.11	.490
80.58	.0271	2569	.5294	.4206	.7949	995	.9884	.12	.664
80.06	.0320	2554	.5536	.4710	.8508	994	.9884	.12	.826
80.41	.0348	2558	.5762	.4934	.8562	989	.9886	.13	.876
80.07	.0366	2555	.5879	.5033	.8562	995	.9884	.11	.896
80.27	.0414	2559	.6096	.5252	.8615	993	.9884	.12	.899
81.07	.0444	2566	.6189	.5409	.8734	979	.9886	.11	.899
80.40	.0473	2559	.6335	.5502	.8688	990	.9884	.12	.899
60.11	.0248	1901	.5113	.3608	.7058	984	.9920	.06	.375
60.10	.0343	1901	.5681	.4845	.8528	985	.9920	.06	.828
60.02	.0438	1901	.6155	.5318	.8641	987	.9920	.06	.868
59.66	.0451	1898	.6180	.5369	.8687	991	.9895	.05	.874
59.70	.0499	1898	.6307	.5511	.8738	990	.9895	.06	.854
59.77	.0557	1898	.6407	.5653	.8824	987	.9895	.06	.824
Nominal inlet temperature, 1060° R; combustor configuration B									
100.25	0.0245	3305	0.5116	0.3825	0.7475	1055	0.9882	0.12	0.539
100.42	.0300	3295	.5442	.4525	.8316	1052	.9884	.15	.830
100.58	.0349	3309	.5745	.4862	.8464	1057	.9882	.15	.900
101.37	.0393	3331	.5974	.5074	.8492	1053	.9884	.15	.914
100.49	.0446	3309	.6158	.5283	.8581	1059	.9882	.15	.909
100.19	.0498	3301	.6316	.5465	.8652	1061	.9885	.14	.908
100.29	.0540	3300	.6415	.5582	.8701	1068	.9886	.15	.887
80.38	.0250	2648	.5106	.3799	.7441	1060	.9884	.12	.516
79.96	.0300	2618	.5462	.4473	.8189	1046	.9888	.12	.793
80.52	.0349	2650	.5645	.4800	.8503	1058	.9984	.12	.865
80.32	.0401	2633	.6035	.5108	.8464	1053	.9899	.12	.908
80.63	.0448	2651	.6156	.5277	.8572	1056	.9885	.12	.902
80.46	.0501	2639	.6336	.5468	.8630	1055	.9903	.12	.890
60.27	.0246	1982	.5076	.3597	.7087	1059	.9895	.06	.402
59.83	.0286	1958	.5383	.4285	.7960	1065	.9925	.05	.686
59.76	.0348	1969	.5812	.4738	.8443	1063	.9895	.06	.838
59.82	.0381	1959	.5840	.4941	.8462	1056	.9925	.06	.858
59.81	.0446	1970	.6107	.5193	.8504	1062	.9895	.05	.866
59.78	.0498	1958	.6302	.5429	.8614	1058	.9922	.06	.874
59.84	.0556	1971	.6388	.5535	.8666	1062	.9895	.05	.844
Nominal inlet temperature, 1210° R; combustor configuration A									
119.69	0.0240	4231	0.5053	0.3919	0.7755	1220	0.9881	0.18	0.708
119.96	.0298	4237	.5405	.4449	.8231	1218	.9881	.18	.926
119.93	.0348	4236	.5595	.4658	.8325	1218	.9881	.18	.920
119.99	.0384	4238	.5757	.4847	.8418	1218	.9881	.18	.932
119.70	.0400	4217	.5786	.4885	.8443	1212	.9881	.17	.933
119.95	.0449	4238	.5998	.5038	.8402	1219	.9881	.17	.920
119.92	.0493	4237	.6110	.5183	.8482	1219	.9881	.18	.919
119.56	.0499	4212	.6097	.5226	.8571	1212	.9881	.16	.922
100.20	.0250	3543	.5064	.3997	.7893	1221	.9881	.15	.740
100.11	.0299	3542	.5404	.4447	.8229	1222	.9881	.15	.923
100.97	.0301	3569	.5428	.4397	.8100	1213	.9881	.16	.877
100.31	.0344	3542	.5570	.4636	.8328	1217	.9881	.14	.919
100.68	.0389	3549	.5726	.4849	.8489	1213	.9881	.15	.938
100.11	.0395	3537	.5765	.4857	.8426	1219	.9881	.14	.934
100.20	.0445	3542	.5954	.5025	.8440	1220	.9881	.15	.921
100.25	.0499	3545	.6099	.5182	.8497	1221	.9881	.15	.908
100.63	.0504	3545	.6121	.5233	.8548	1212	.9881	.15	.919
79.98	.0250	2825	.5106	.4000	.7831	1218	.9881	.12	.740
79.99	.0299	2823	.5377	.4350	.8090	1216	.9881	.12	.853
80.01	.0351	2825	.5600	.4690	.8575	1217	.9881	.12	.935
80.22	.0400	2850	.5746	.4876	.8487	1215	.9881	.12	.930
80.33	.0449	2835	.5982	.5065	.8449	1216	.9881	.12	.927
80.30	.0502	2833	.6100	.5203	.8530	1215	.9881	.12	.908
59.97	.0250	2116	.5137	.4003	.7792	1222	.9906	.09	.736
59.87	.0250	2116	.5132	.4006	.7808	1222	.9908	.09	.740
60.07	.0300	2116	.5425	.4376	.8066	1218	.9908	.09	.860
60.38	.0300	2111	.5424	.4387	.8087	1211	.9954	.10	.850
60.04	.0348	2115	.5570	.4643	.8336	1218	.9908	.09	.906
60.36	.0396	2111	.5732	.4846	.8455	1212	.9954	.09	.899
60.02	.0398	2116	.5737	.4844	.8443	1220	.9908	.09	.915
60.07	.0453	2116	.5992	.5033	.8399	1218	.9908	.09	.901
60.33	.0496	2111	.6101	.5178	.8486	1213	.9954	.09	.883
60.07	.0498	2116	.6101	.5170	.8474	1218	.9906	.09	.894

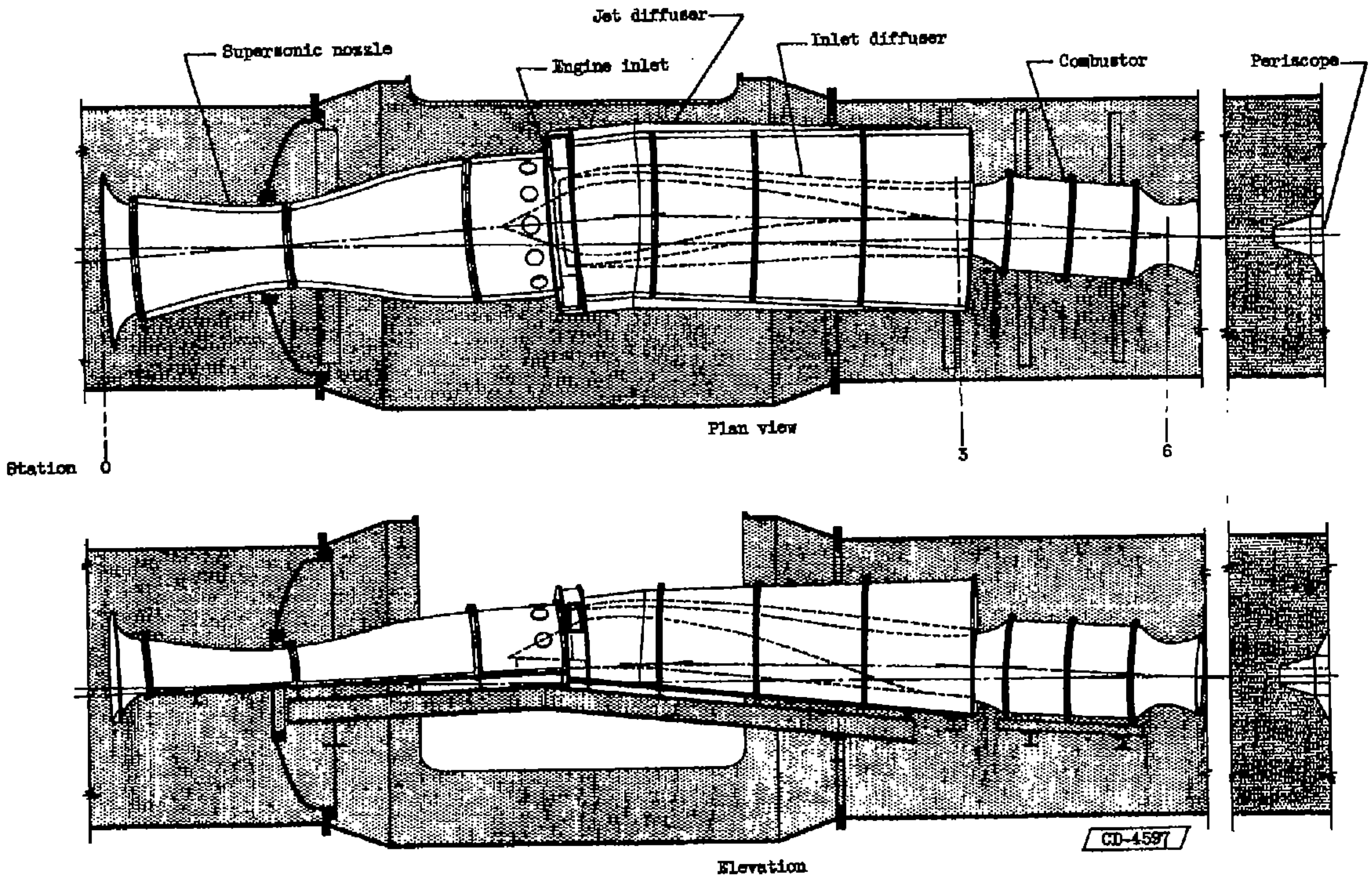
4127

4127

CD-2 back

TABLE III. - INLET CONDITIONS AND COMBUSTOR PERFORMANCE DATA FOR SHELL UMF, GRADE C, FUEL

Engine airflow, $W_{a,0}$, lb/sec	Fuel-air ratio, f/a	Free-stream total pressure, P_0, lb/sq ft abs	Diffuser total-pressure recovery, P_3/P_0	Engine total-pressure ratio, P_6/P_0	Combustor total-pressure ratio, P_6/P_3	Engine inlet total temperature, T_0, °R	Engine airflow parameter, K	Pilot fuel flow, lb/sec	Combustion efficiency, η_b
Nominal inlet temperature, 990° R; combustor configuration B									
121.02	0.0245	3845	0.5035	0.3537	0.7025	986	0.9883	0.13	0.347
120.75	.0301	3840	.5492	.4599	.8374	988	.9883	.11	.811
121.12	.0361	3852	.5911	.5023	.8498	988	.9883	.16	.895
120.73	.0394	3843	.6071	.5176	.8526	990	.9883	.15	.901
101.02	.0259	3214	.5072	.3936	.7761	989	.9885	.13	.533
100.74	.0312	3205	.5532	.4633	.8376	990	.9885	.14	.795
100.80	.0363	3205	.5897	.5033	.8534	988	.9885	.15	.895
100.90	.0402	3203	.6060	.5189	.8563	985	.9885	.15	.886
100.92	.0452	3204	.6174	.5381	.8716	985	.9885	.14	.876
101.09	.0486	3209	.6370	.5550	.8713	985	.9885	.14	.891
80.24	.0260	2551	.5088	.3916	.7696	990	.9895	.12	.519
80.41	.0312	2554	.5497	.4593	.8355	988	.9895	.11	.776
80.34	.0366	2552	.5854	.5000	.8541	988	.9895	.12	.869
80.55	.0420	2552	.6113	.5263	.8609	983	.9895	.12	.879
80.77	.0472	2554	.6253	.5458	.8729	979	.9895	.11	.871
80.36	.0500	2554	.6370	.5595	.8783	989	.9895	.10	.888
80.39	.0505	2555	.6407	.5550	.8662	989	.9895	.11	.861
60.09	.0256	1905	.5102	.3612	.7078	989	.9920	.06	.367
60.06	.0306	1904	.5436	.4530	.8329	986	.9920	.06	.748
60.18	.0356	1903	.5723	.4898	.8558	984	.9920	.06	.829
60.03	.0411	1899	.6056	.5166	.8530	985	.9920	.05	.844
60.06	.0466	1901	.6176	.5376	.8705	986	.9920	.05	.839
59.94	.0516	1899	.6298	.5503	.8737	988	.9920	.05	.814
59.87	.0591	1897	.6410	.5640	.8799	990	.9920	.06	.761
Nominal inlet temperature, 1060° R; combustor configuration B									
100.73	0.0253	3312	0.5100	0.3810	0.7472	1056	0.9884	0.11	0.514
100.70	.0312	3309	.5470	.4560	.8337	1055	.9884	.15	.821
100.73	.0359	3310	.5804	.4909	.8459	1055	.9884	.15	.905
100.79	.0403	3309	.5981	.5062	.8464	1053	.9884	.14	.883
100.85	.0458	3309	.6177	.5295	.8571	1052	.9884	.13	.889
100.85	.0525	3309	.6371	.5609	.8648	1052	.9884	.12	.874
80.74	.0260	2652	.5087	.3880	.7828	1054	.9886	.12	.538
80.76	.0310	2651	.5417	.4493	.8294	1053	.9886	.12	.784
80.53	.0365	2645	.5743	.4870	.8479	1054	.9886	.12	.866
80.63	.0417	2645	.6015	.5115	.8504	1052	.9886	.11	.880
80.63	.0471	2645	.6212	.5342	.8600	1052	.9886	.11	.885
80.63	.0525	2645	.6363	.5497	.8639	1052	.9886	.12	.867
60.79	.0252	1998	.5065	.3609	.7125	1063	.9918	.06	.401
60.21	.0304	1979	.5422	.4426	.8164	1063	.9918	.05	.757
59.76	.0361	1959	.5661	.4803	.8485	1057	.9918	.05	.834
59.78	.0413	1959	.5963	.5043	.8452	1056	.9918	.05	.848
59.78	.0462	1959	.6105	.5237	.8579	1056	.9918	.06	.849
59.78	.0517	1959	.6314	.5431	.8601	1056	.9918	.05	.843
59.78	.0580	1959	.6427	.5574	.8674	1056	.9918	.05	.812
Nominal inlet temperature, 1210° R; combustor configuration A									
120.58	0.0254	4243	0.5088	0.4040	0.7939	1209	0.9881	0.20	0.748
120.66	.0312	4246	.5464	.4510	.8254	1209	.9881	.18	.917
120.68	.0365	4249	.5625	.4733	.8414	1210	.9881	.19	.918
120.71	.0418	4250	.5854	.4932	.8424	1210	.9881	.19	.919
120.93	.0439	4254	.5910	.5000	.8461	1208	.9881	.17	.911
100.80	.0258	3547	.5171	.4096	.7923	1209	.9881	.15	.783
100.66	.0312	3542	.5443	.4512	.8288	1209	.9881	.16	.920
100.66	.0363	3545	.5605	.4705	.8395	1211	.9881	.16	.909
100.77	.0405	3546	.5773	.4876	.8447	1209	.9881	.15	.914
100.80	.0468	3547	.6016	.5089	.8458	1209	.9881	.16	.904
100.97	.0486	3552	.6087	.5135	.8437	1208	.9881	.16	.891
100.60	.0540	3539	.6197	.5284	.8527	1208	.9881	.16	.882
80.02	.0264	2824	.5117	.4044	.7903	1216	.9881	.13	.731
80.02	.0316	2824	.5457	.4494	.8235	1216	.9881	.12	.902
80.05	.0364	2824	.5602	.4695	.8382	1215	.9881	.12	.904
80.05	.0413	2824	.5765	.4911	.8520	1215	.9881	.13	.923
80.03	.0466	2822	.5982	.5053	.8448	1214	.9881	.13	.893
80.03	.0530	2822	.6141	.5245	.8540	1214	.9881	.13	.883
59.79	.0313	2106	.5456	.4430	.8120	1218	.9909	.10	.859
59.85	.0366	2106	.5565	.4663	.8379	1216	.9909	.09	.874
59.81	.0420	2106	.5788	.4896	.8458	1217	.9909	.10	.890
59.87	.0471	2107	.6009	.5059	.8420	1216	.9909	.10	.881
59.84	.0521	2107	.6122	.5206	.8504	1217	.9909	.11	.873



Station	Total-pressure tubes	Static-pressure tubes	Thermocouples	Wall static-pressure orifices
0	18	0	14	0
3	44	38	21	6
6	33	0	0	0

Figure 1. - Free-jet installation of 48-inch ram-jet engine showing location and amount of instrumentation.

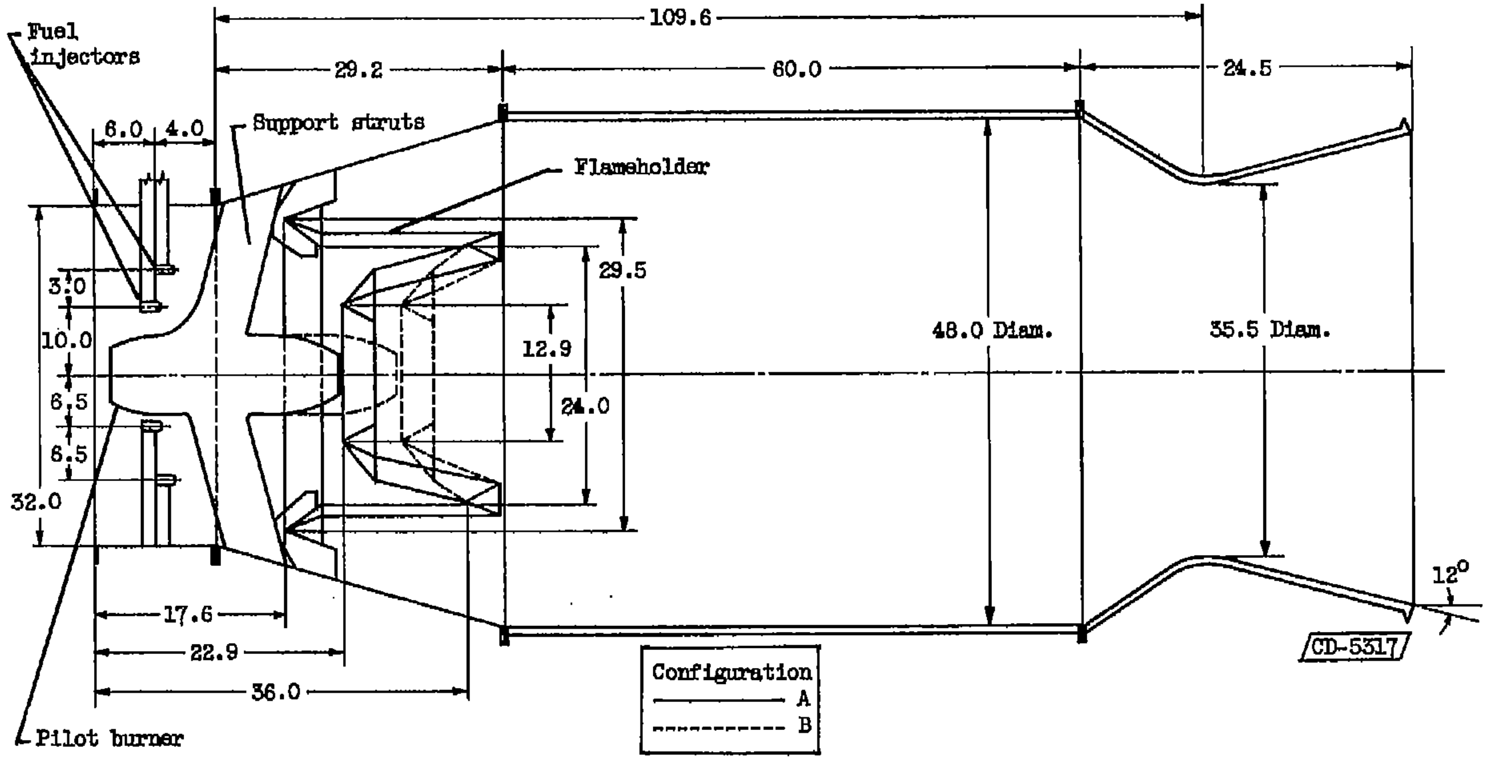
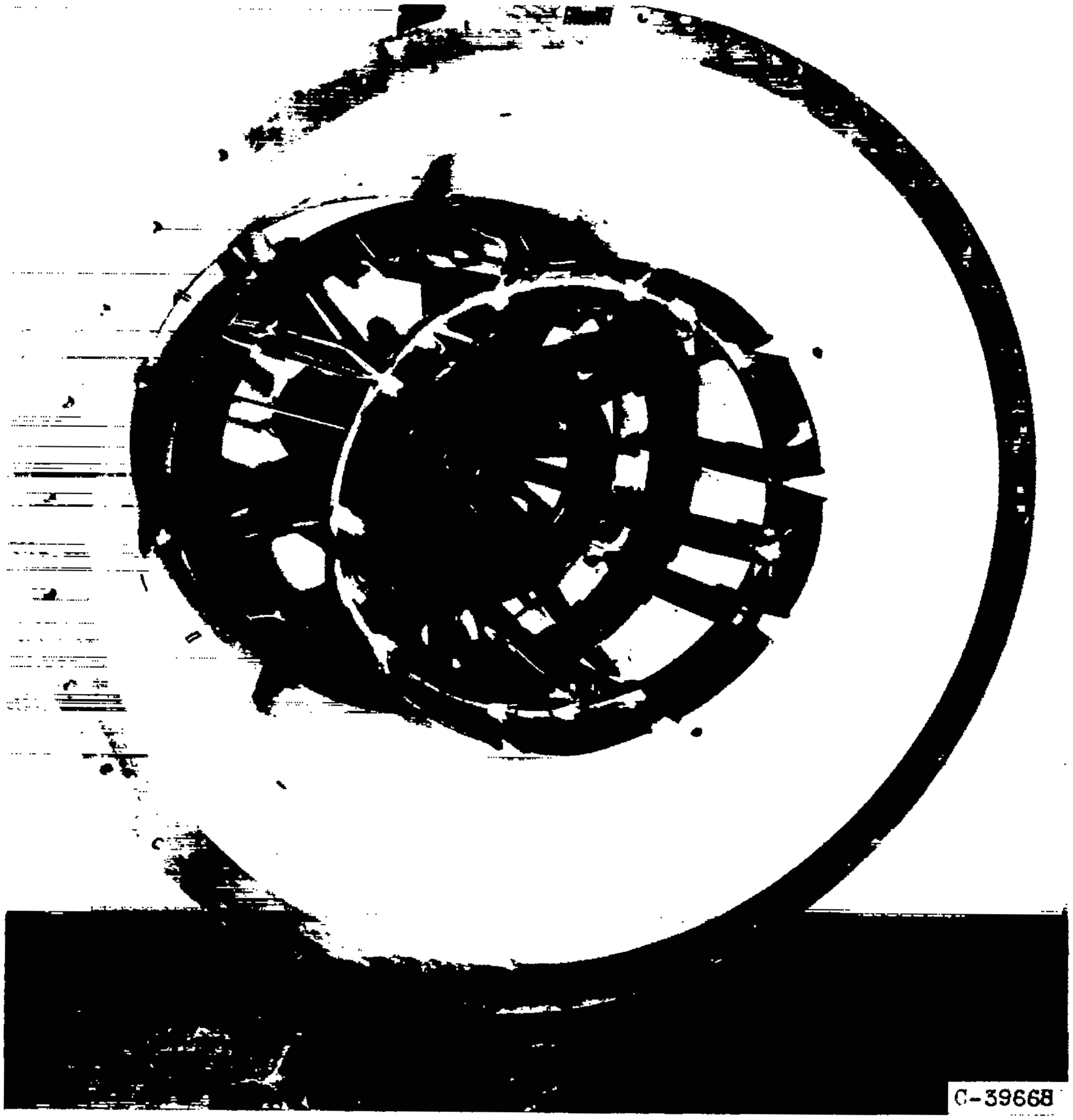


Figure 2. - Cross section of heavy-duty version of XRJ47-W-9 ram-jet engine. (All dimensions in inches.)

4127



(a) Configuration A.

Figure 3. - Downstream view of heavy-duty XRJ47-W-9 ram-jet engine combustor.

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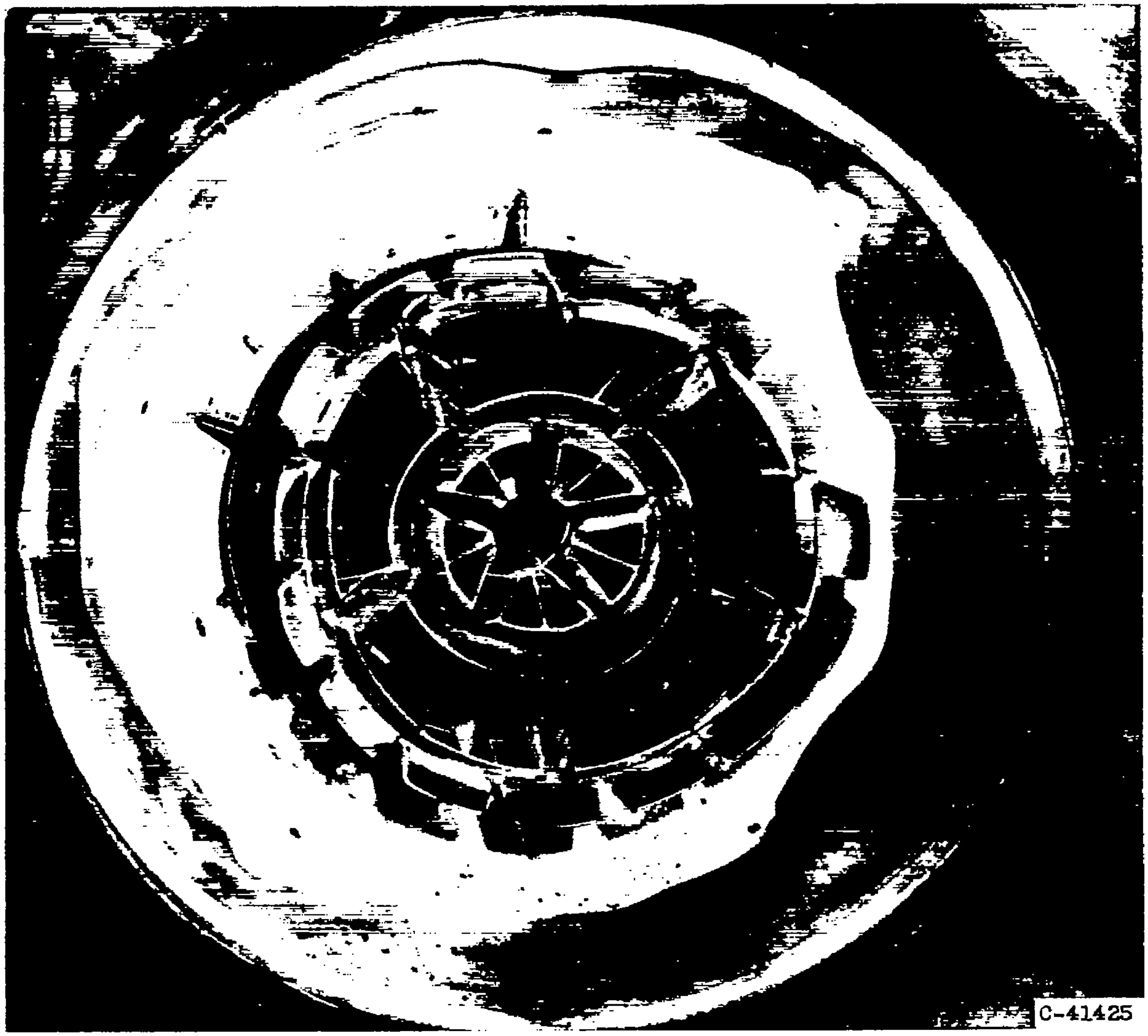

(b) Configuration B.

Figure 3. - Concluded. Downstream view of heavy-duty XRJ47-W-9 ram-jet engine combustor.

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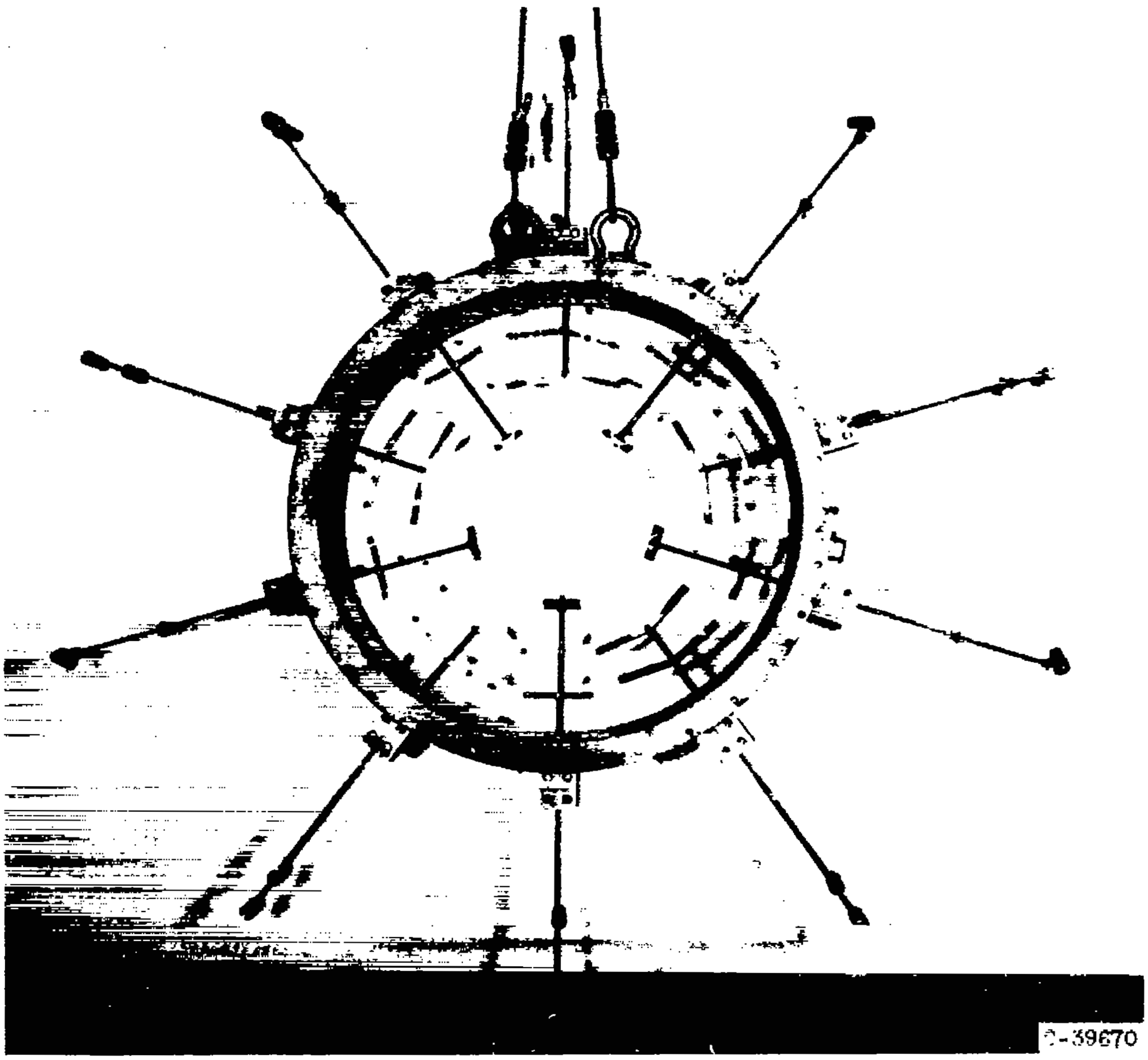

Figure 4. - Heavy-duty adjustable fuel-spray bars for XRJ47-W-9 ram-jet engine.

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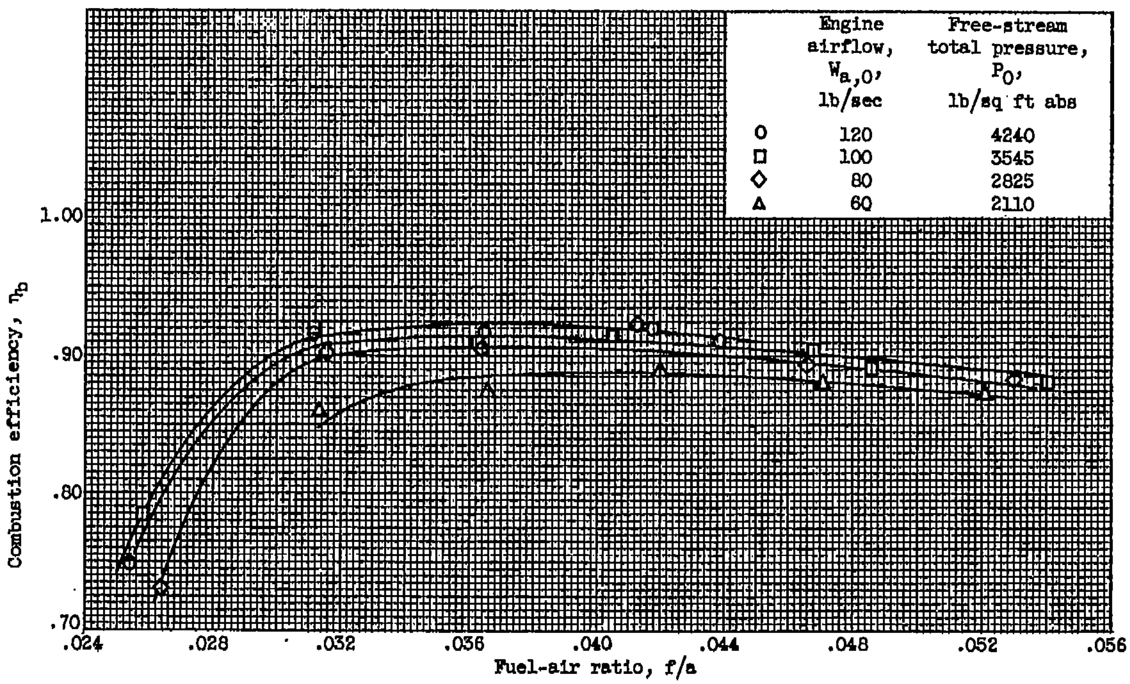
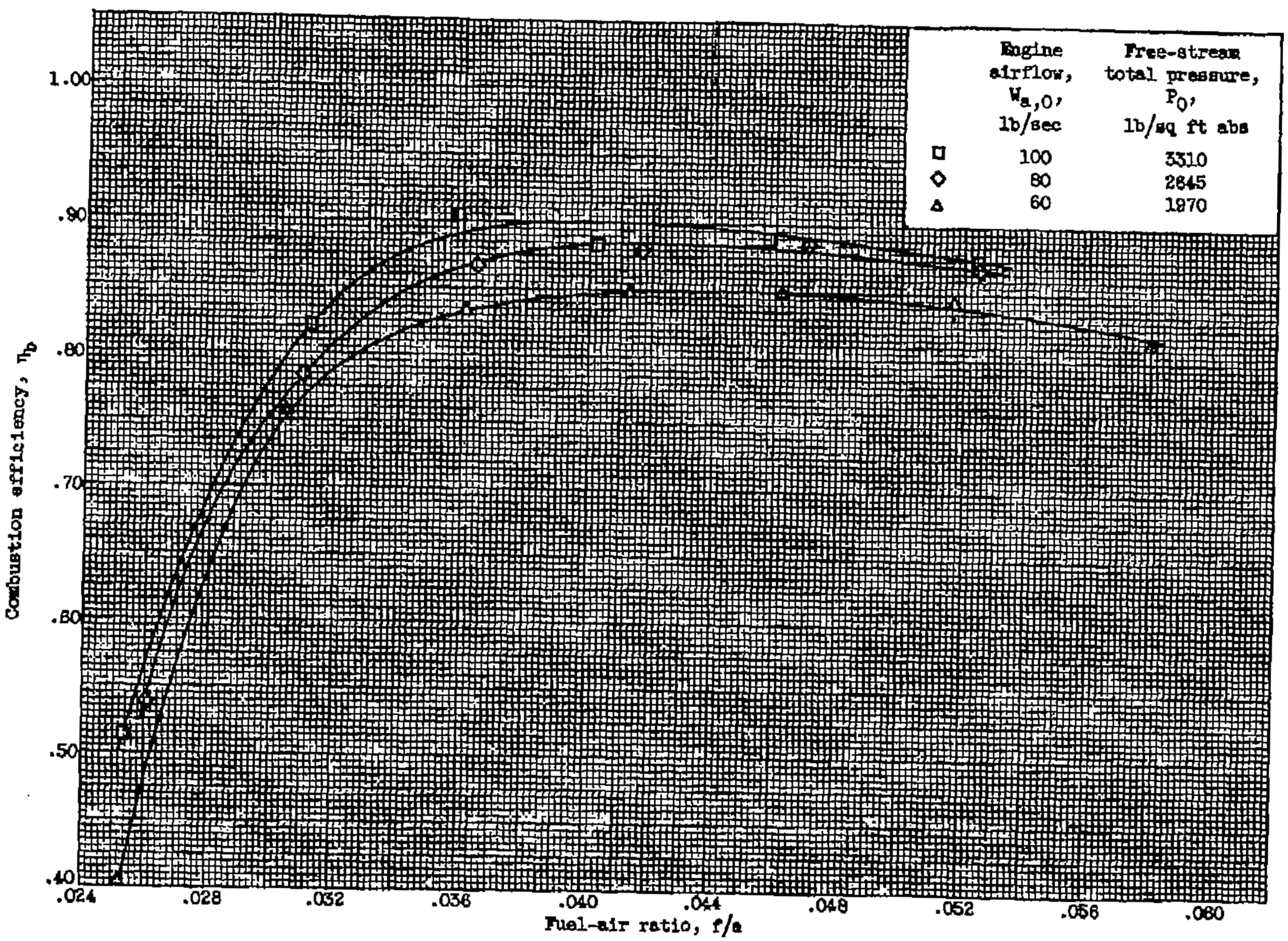


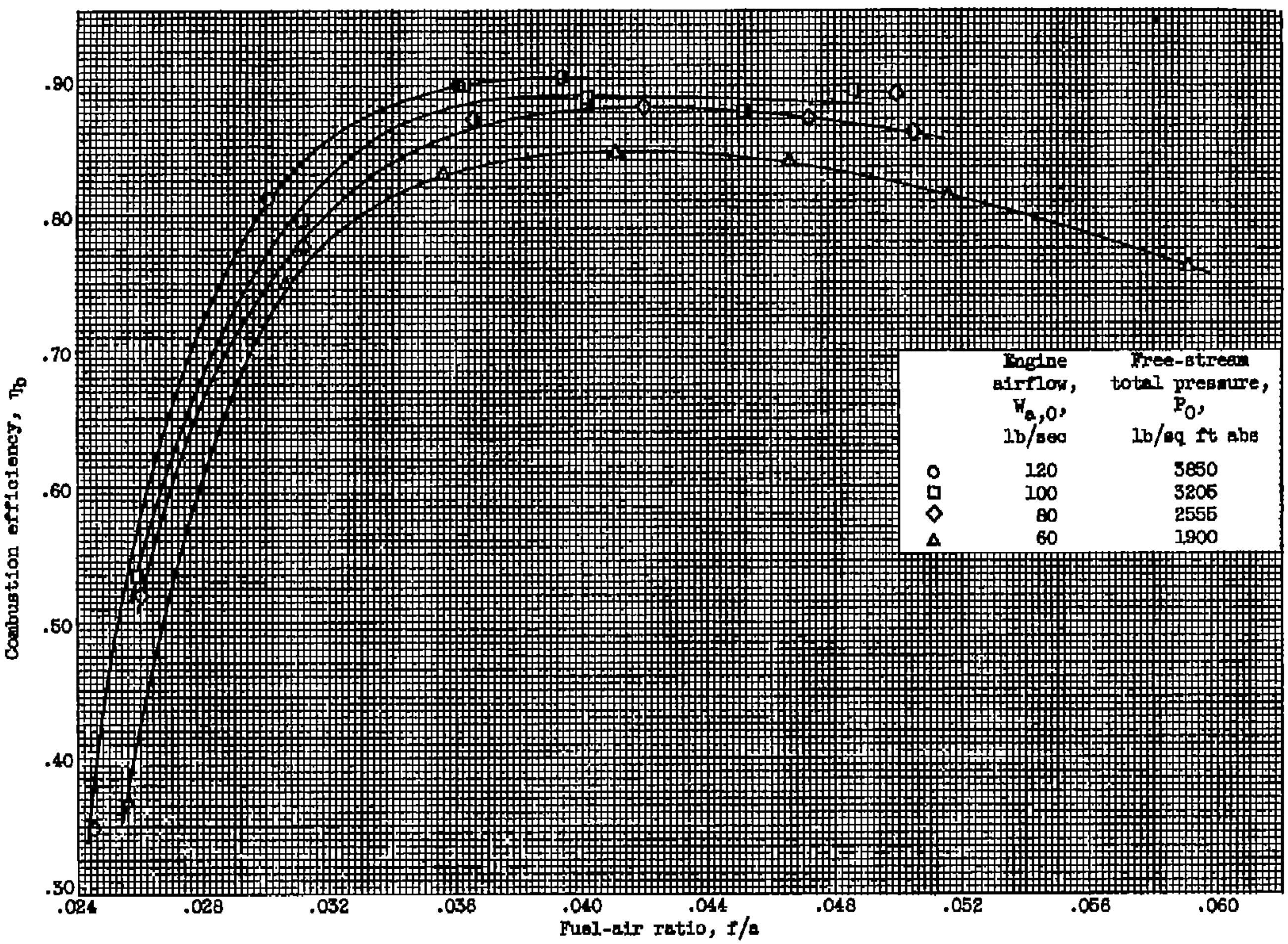
(a) Temperature, 1210° R. Combustor configuration A.

Figure 5. - Combustion efficiencies obtained with Shell UMF, grade C, fuel over a range of pressures at various nominal inlet total temperatures.



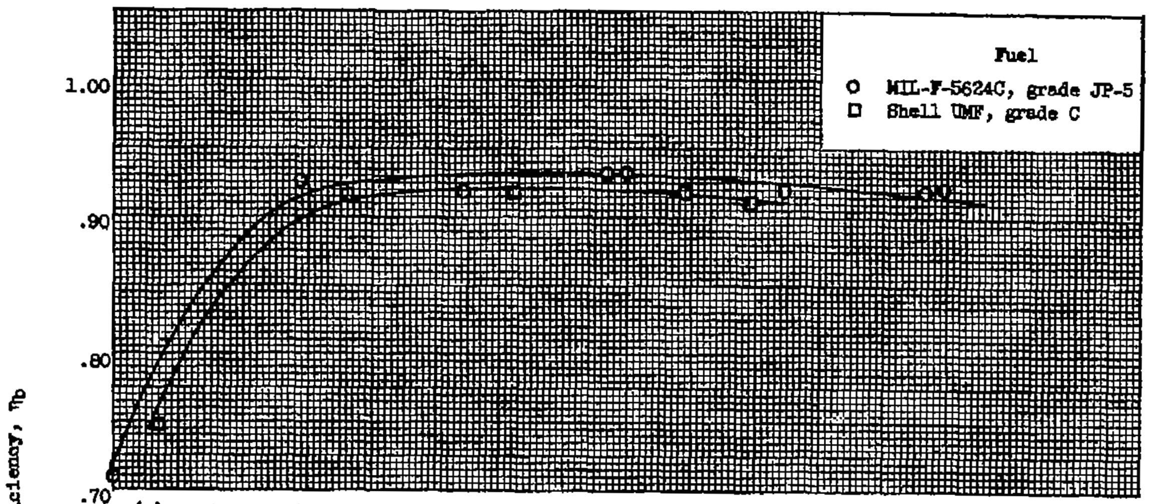
(b) Temperature, 1060° R. Combustor configuration B.

Figure 5. Continued. Combustion efficiencies obtained with Shell UMF, grade C, fuel over a range of pressures at various nominal inlet total temperatures.

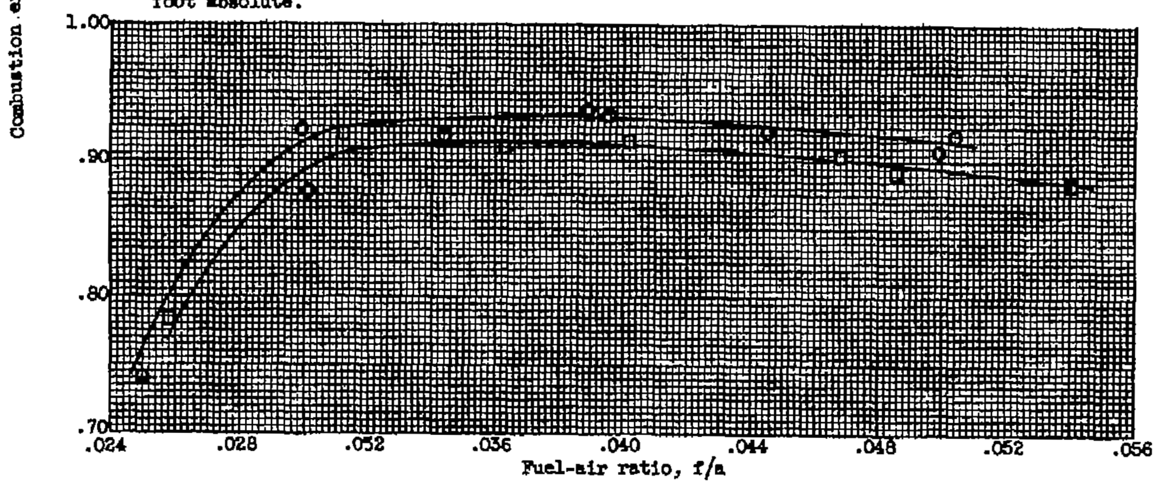


(c) Temperature, 990° R. Combustor configuration B.

Figure 5. - Concluded. Combustion efficiencies obtained with Shell UMF, grade C, fuel over a range of pressures at various nominal inlet total temperatures.

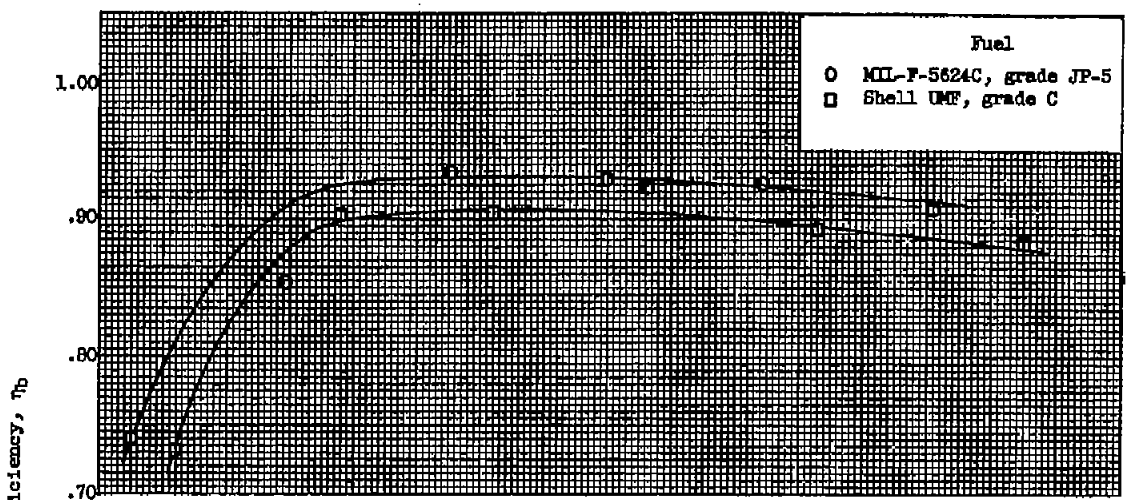


(a) Engine airflow, 120 pounds per second; free-stream total pressure, 4240 pounds per square foot absolute.

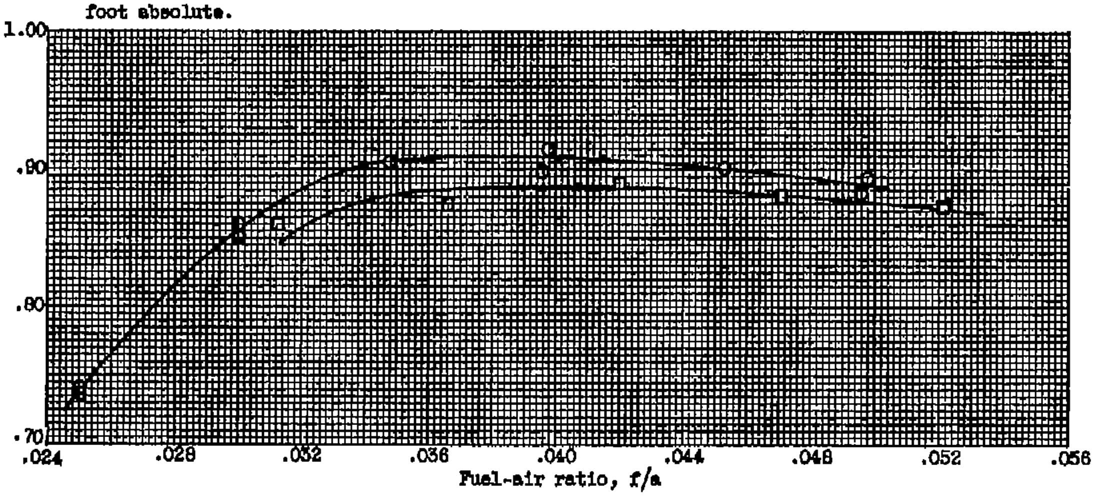


(b) Engine airflow, 100 pounds per second; free-stream total pressure, 3545 pounds per square foot absolute.

Figure 6. - Comparison of combustion efficiencies obtained with Shell UMF, grade C, and MIL-F-5624C, grade JP-5, fuels at a nominal inlet total temperature of 1210° R. Combustor configuration A.

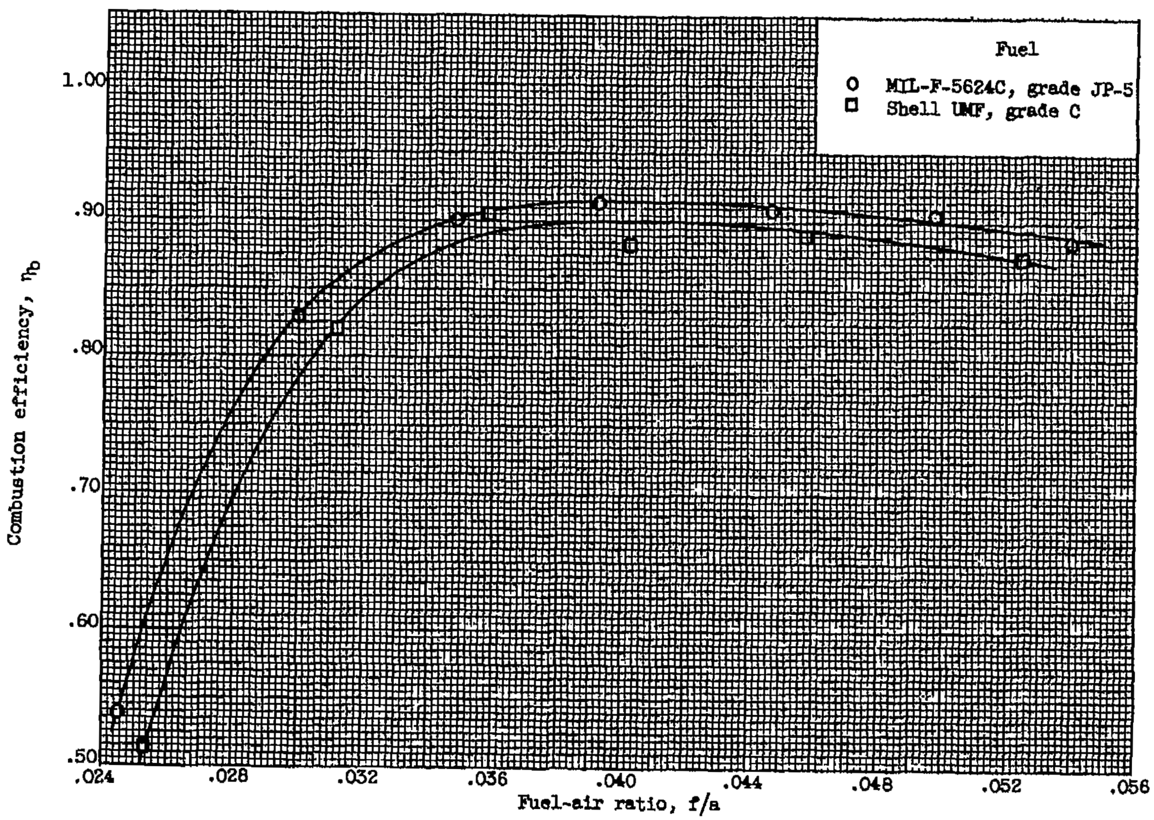


(c) Engine airflow, 80 pounds per second; free-stream total pressure, 2825 pounds per square foot absolute.



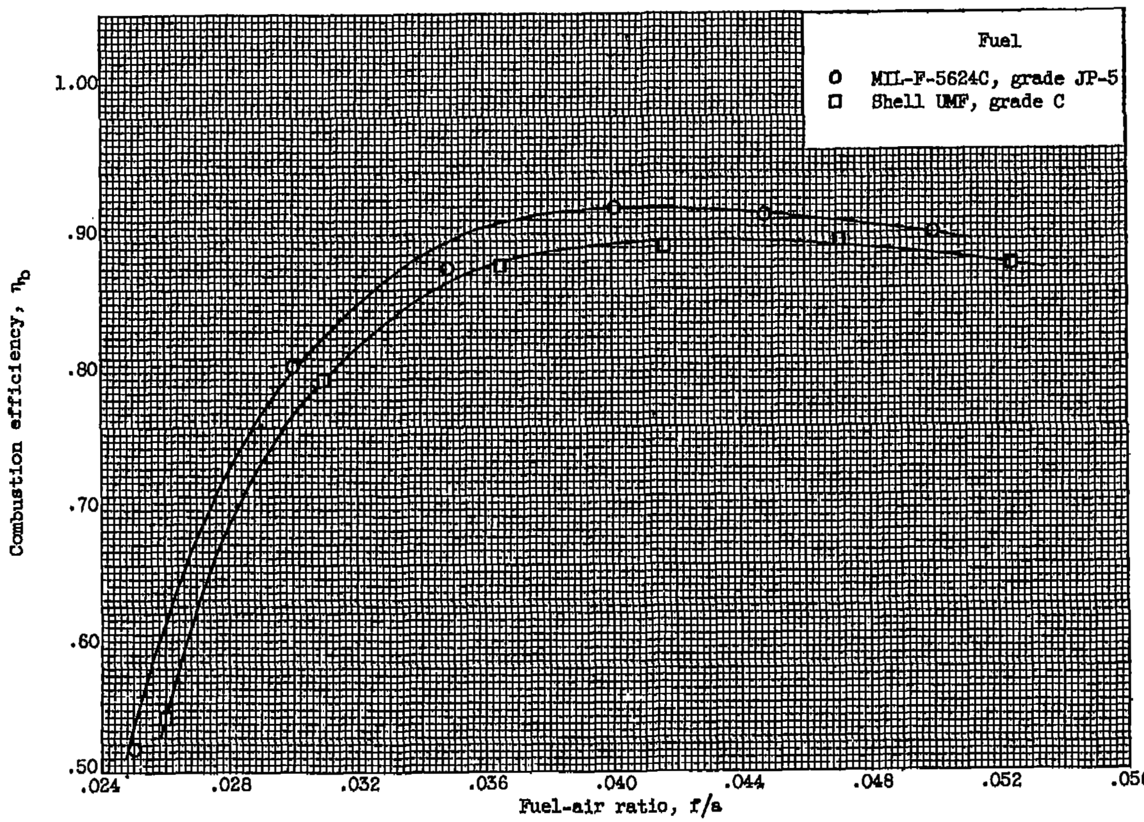
(d) Engine airflow, 80 pounds per second; free-stream total pressure, 2110 pounds per square foot absolute.

Figure 6. - Concluded. Comparison of combustion efficiencies obtained with Shell UMF, grade C, and MIL-F-5624C, grade JP-5, fuels at a nominal inlet-total temperature of 1210° R. Combustor configuration A.



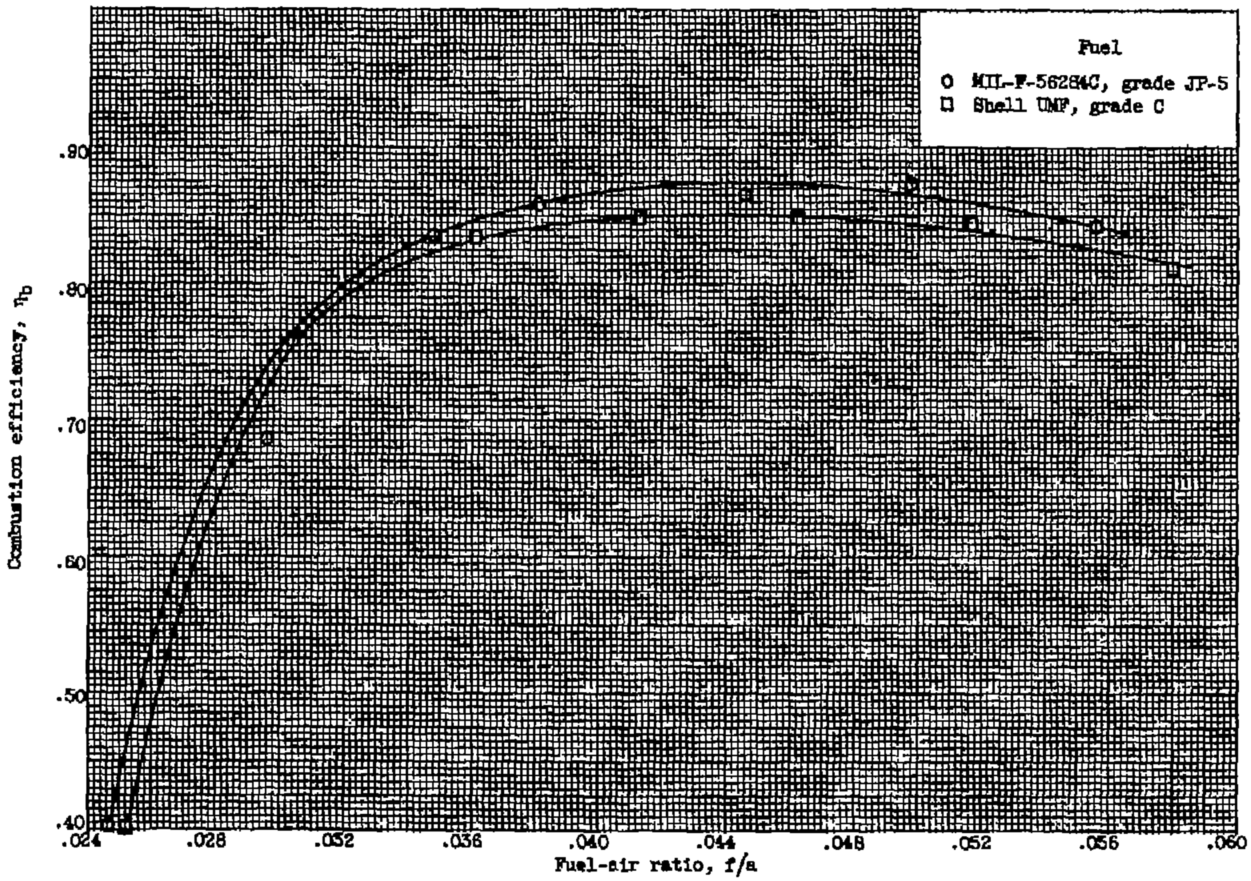
(a) Engine airflow, 100 pounds per second; free-stream total pressure, 3310 pounds per square foot absolute.

Figure 7. - Comparison of combustion efficiencies obtained with Shell UMF, grade C, and MIL-F-5624C, grade JP-5, fuels at a nominal inlet total temperature of 1060° R. Combustor configuration B.



(b) Engine airflow, 80 pounds per second; free-stream total pressure, 2645 pounds per square foot absolute.

Figure 7. - Continued. Comparison of combustion efficiencies obtained with Shell UMF, grade C, and MIL-F-5624C, grade JP-5, fuels at a nominal inlet total temperature of 1060° R. Combustor configuration B.



(c) Engine airflow, 60 pounds per second; free-stream total pressure, 1970 pounds per square foot absolute.

Figure 7. - Concluded. Comparison of combustion efficiencies obtained with Shell UMF, grade C, and MIL-F-5624C, grade JP-5, fuels at a nominal inlet total temperature of 1060° R. Combustor configuration B.

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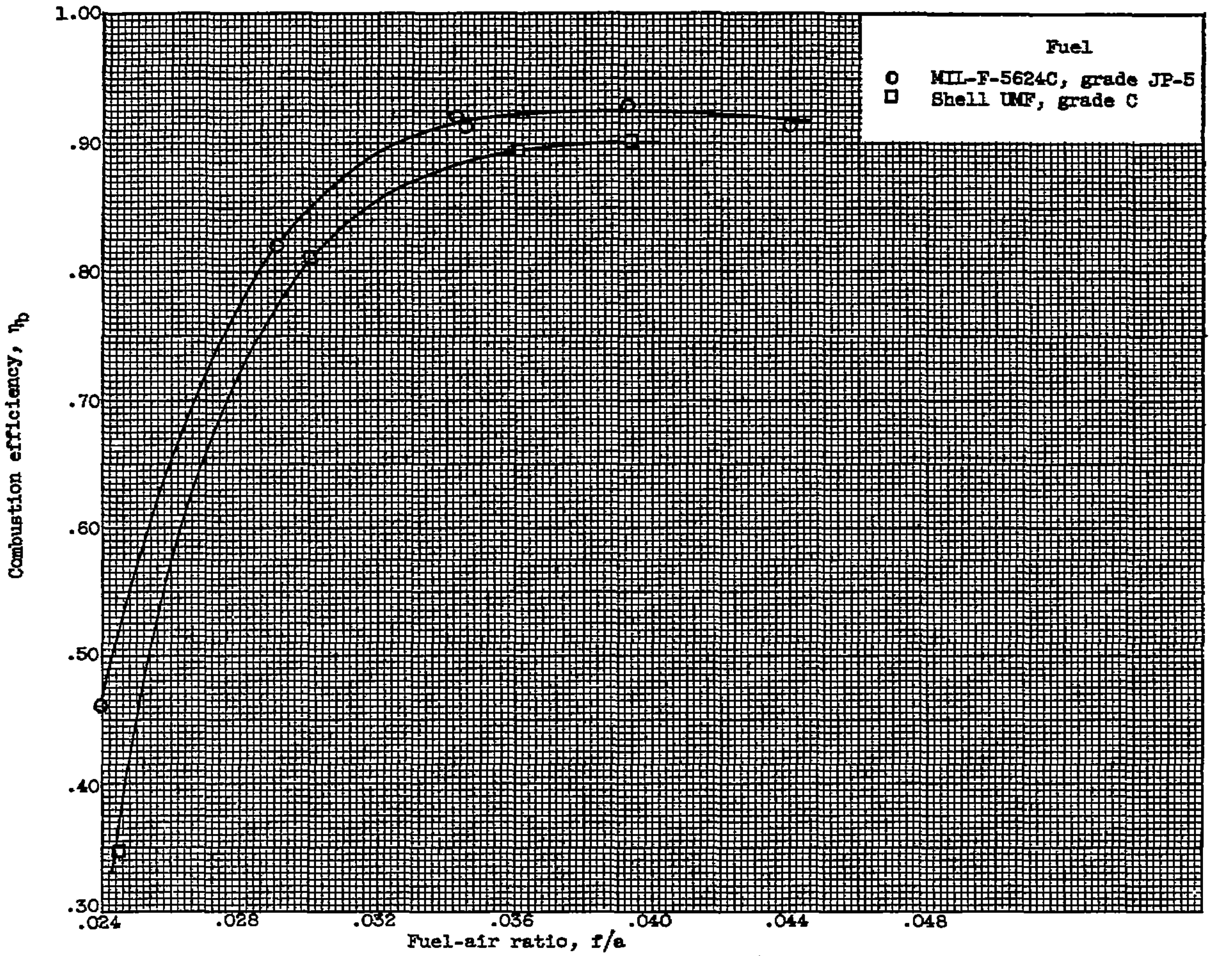

(a) Engine airflow, 120 pounds per second; free-stream total pressure, 3850 pounds per square foot absolute.

Figure 8. - Comparison of combustion efficiencies obtained with Shell UMF, grade C, and MIL-F-5624C, grade JP-5, fuels at a nominal inlet total temperature of 990° R. Combustor configuration B.

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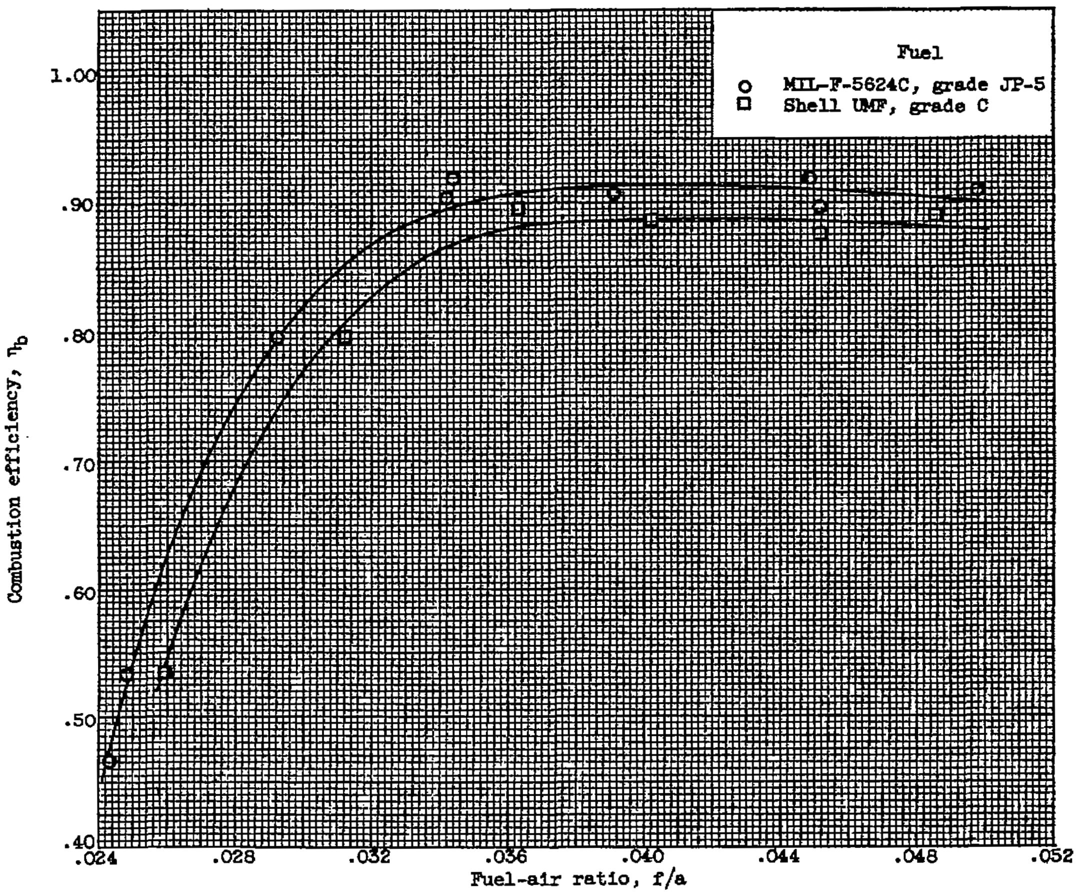

(b) Engine airflow, 100 pounds per second; free-stream total pressure, 3205 pounds per square foot absolute.

Figure 8. - Continued. Comparison of combustion efficiencies obtained with Shell UMF, grade C, and MIL-F-5624C, grade JP-5, fuels at a nominal inlet total temperature of 990° R. Combustor configuration B.

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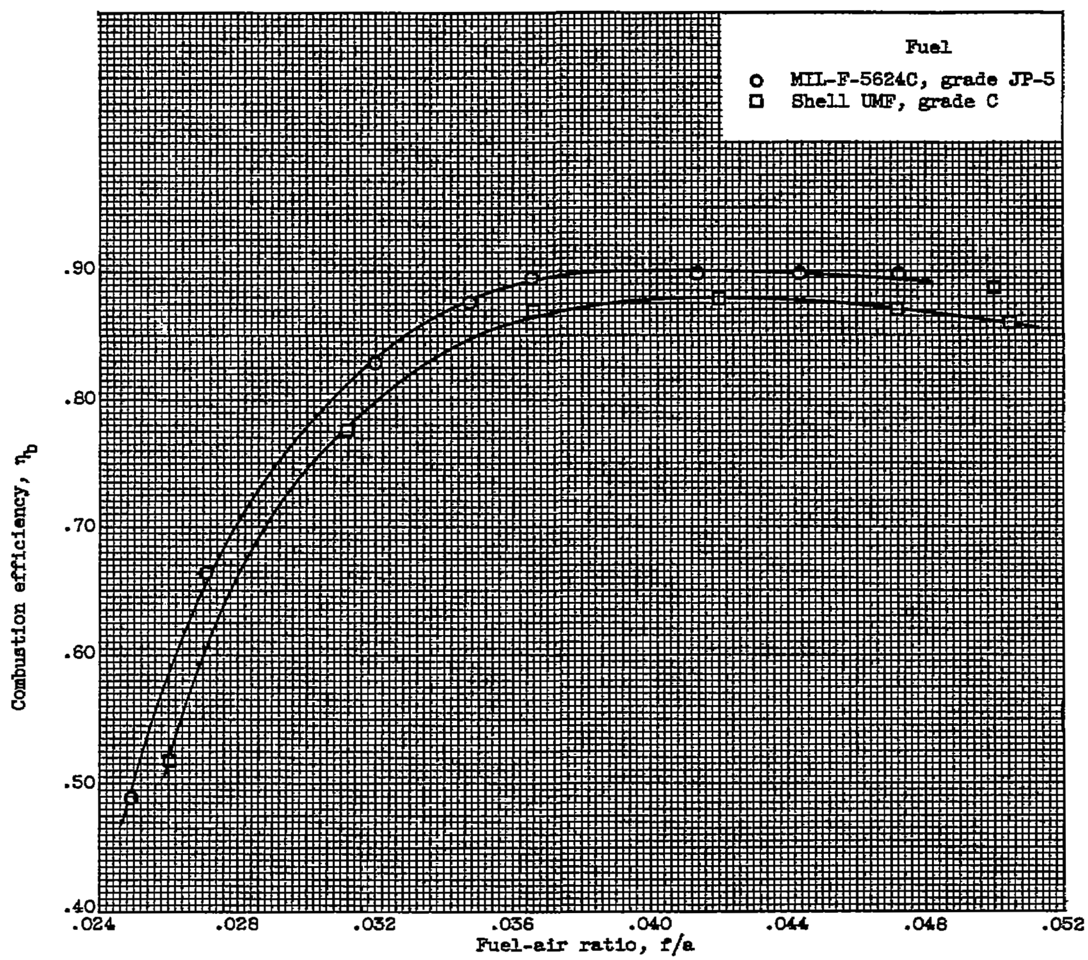
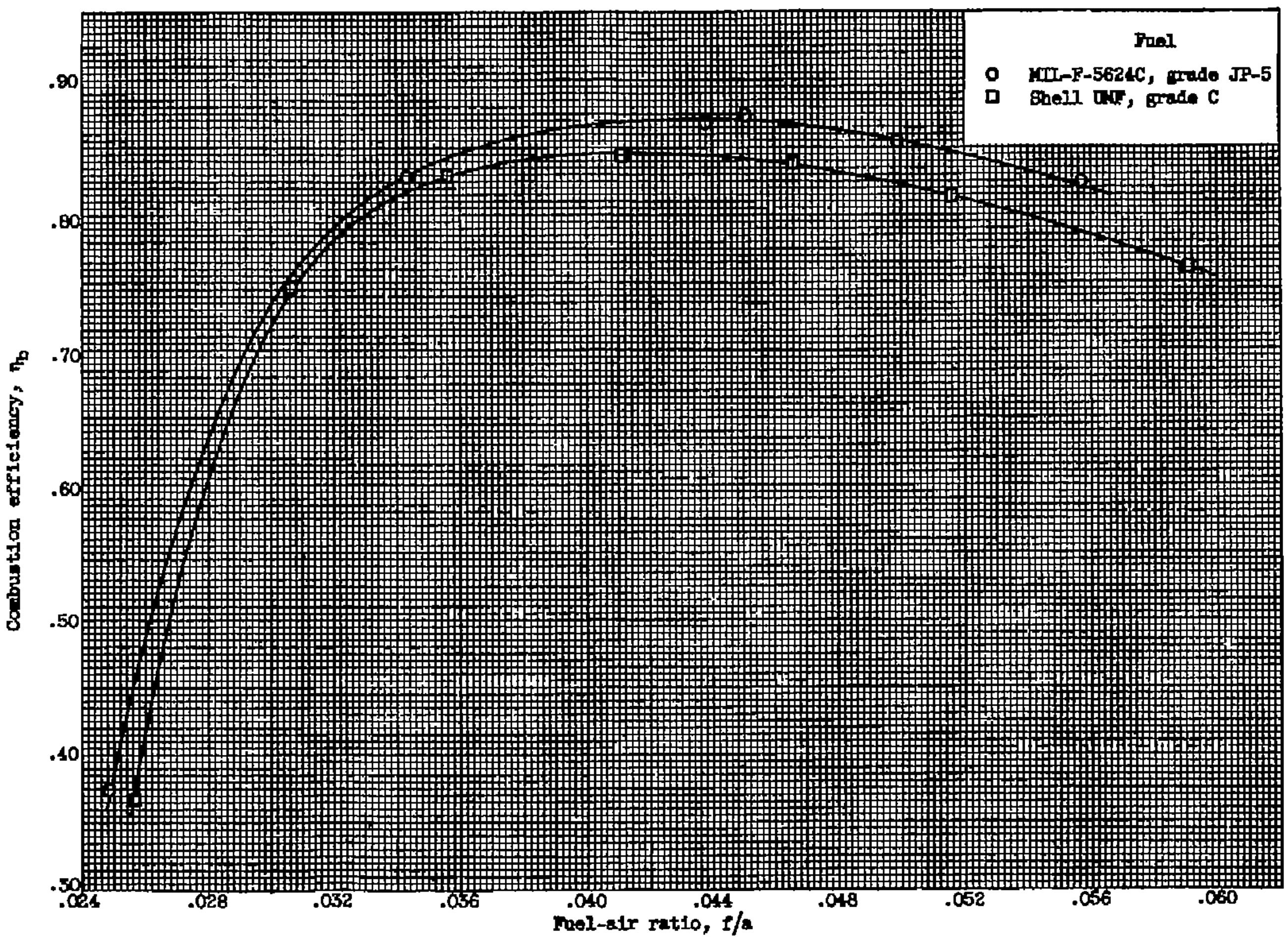


(c) Engine airflow, 80 pounds per second; free-stream total pressure, 2555 pounds per square foot absolute.

Figure 8. - Continued. Comparison of combustion efficiencies obtained with Shell UMF, grade C, and MIL-F-5624C, grade JP-5, fuels at a nominal inlet total temperature of 990° R. Combustor configuration B.



(d) Engine airflow, 60 pounds per second; free-stream total pressure, 1900 pounds per square foot absolute.

Figure 8. - Concluded. Comparison of combustion efficiencies obtained with Shell UMF, grade C, and MIL-F-5624C, grade JP-5, fuels at a nominal inlet total temperature of 990° R. Combustor configuration B.

4127

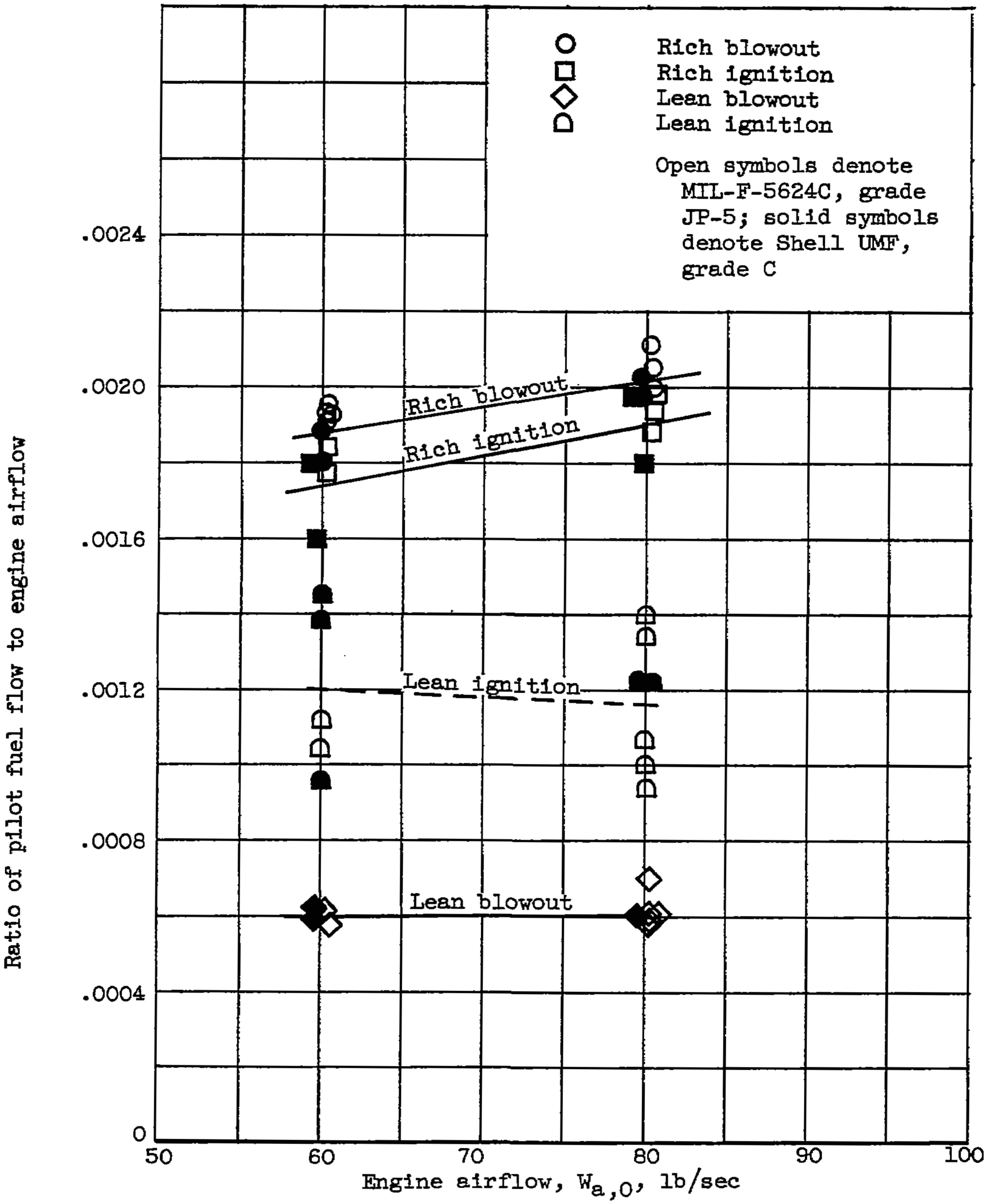


Figure 9. - Comparison of pilot-burner operating limits obtained with Shell UMF, grade C, and MIL-F-5624C, grade JP-5, fuels at a nominal inlet total temperature of 990° R. Combustor configuration B.

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COMPARISON OF THE COMBUSTION PERFORMANCE OF SHELL UMF, GRADE C, AND MIL-F-5624C, GRADE JP-5, FUELS IN A HEAVY-DUTY XRJ47-W-9 RAM-JET ENGINE

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NACA-CLEVELAND

Engines, Ram Jet 3.1.7

Fuels - Relation to Engine Performance 3.4.3

Combustion - Ram-Jet Engines 3.5.2.3

Ranscht, W. G., and Farley, J. M.

COMPARISON OF THE COMBUSTION PERFORMANCE OF SHELL UMF, GRADE C, AND MIL-F-5624C, GRADE JP-5, FUELS IN A HEAVY-DUTY XRJ47-W-9 RAM-JET ENGINE

Abstract

Combustion performance characteristics of Shell UMF, grade C, and MIL-F-5624C, grade JP-5, fuels were compared in a heavy-duty version of the XRJ47-W-9 ram-jet engine. With the engine operating in a 2.75 Mach number free-jet facility, data were obtained with both fuels over a range of fuel-air ratios, engine airflows, and engine-inlet temperatures. The variation of combustion efficiency with fuel-air ratio for the two fuels is compared at the several inlet conditions, and the pilot-burner ignition and operating limits with both fuels are also included.